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PIP-II LB650 RF TESTS AT CEA

PIP-II

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PIP-II SRF TEST PROGRAM GOALS

- Design verification of components and subsystems prototypes, and qualification of production components
  - power coupler conditioning & dressed cavity tests at high RF power
  - should ideally precede final design and production procurements
  - will need dedicated 650 MHz power sources and upgrade of horizontal cryostat

- Comprehensive testing of at least 1st LB650 cryomodule before shipping to USA
  - enables to address global cryomodules performance risks
  - mandatory to validate transport scheme, by comparing in detail performance of cryomodule before/after transportation
  - Will need dedicated 650 MHz power sources and upgrade of LHe cryoplant and wave guides in cryomodule test bunker

CEA RF TESTS INFRASTRUCTURES

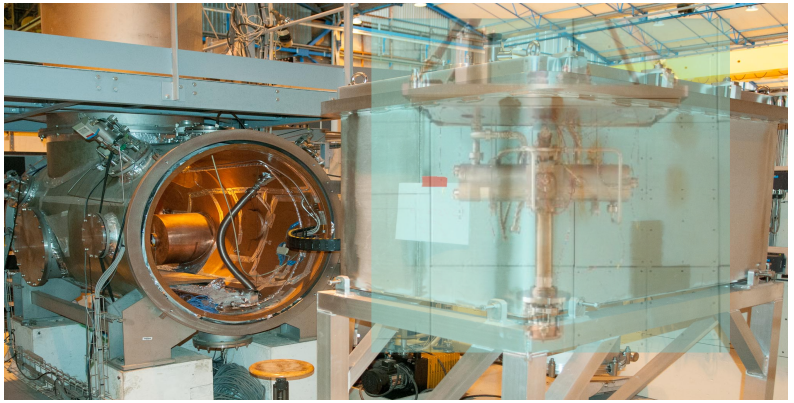
- SupraTech-CryoHF RF test platform:
  - Helial liquid helium liquefier (140l/h) 4K and 2K + 3 2000l Dewar's

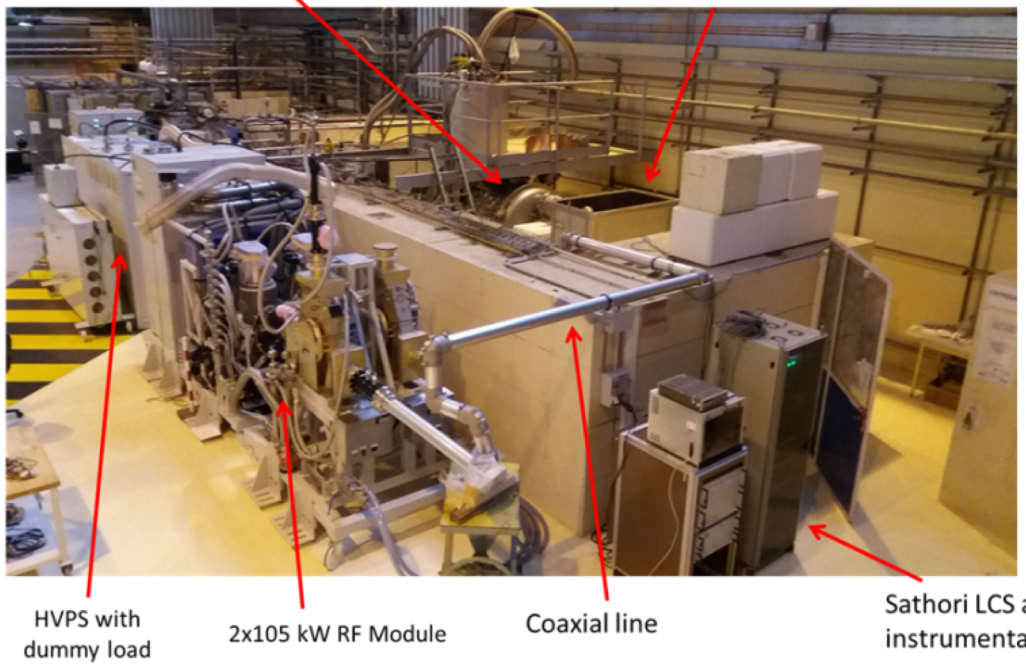
  - Two vertical cryostats (0.45m Φ, 1m long; 0.7m Φ, 1.9 m long) for low power qualification (Q°, E_{acc}), < 2μT remnant field
  - One horizontal cryostat (CryHoLab, 0.7 m Φ, 1.5 m long) for high power dressed cavity qualification up to cryo loads of 80W

CEA RF TESTS INFRASTRUCTURES

Vertical cryostats

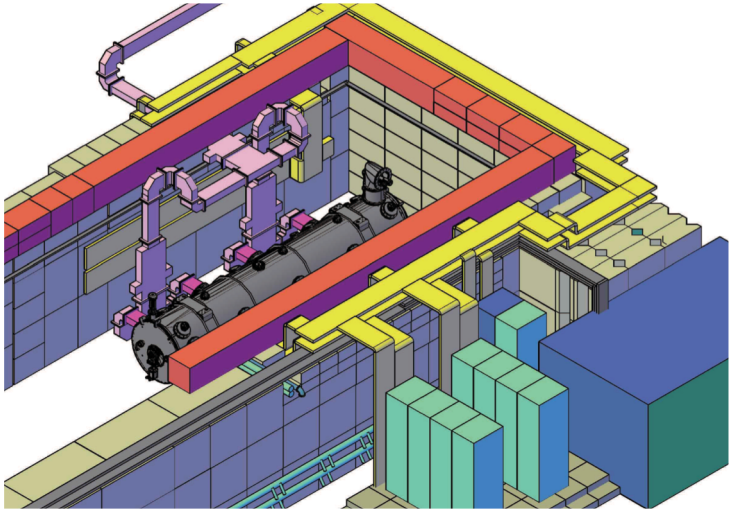
Horizontal cryostats





CEA RF TESTS INFRASTRUCTURES

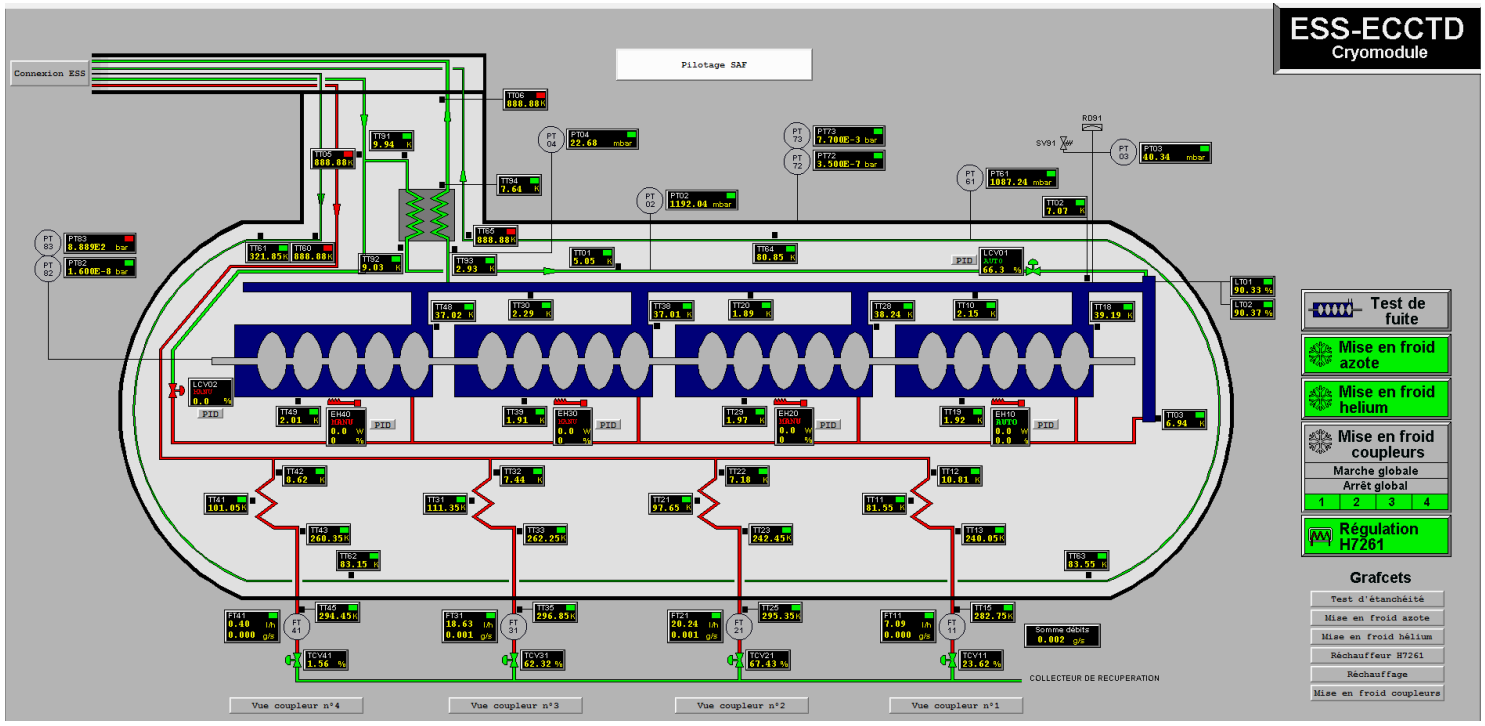
- Several radiologically shielded bunkers, one equipped with LHe cryo cooling capacities up to 80W, used now for ESS and SARAF, then PIP-II



- Several high power RF sources (352 MHz, 704 MHz, 1.3 GHz) unfortunately not useful for PIP-II 650 MHz frequency
  -> will need to purchase dedicated 650 MHz SSA RF power sources

CEA RF TESTS INFRASTRUCTURES

- ESS/SARAF bunker fully instrumented with RF LPS and EPICS C/C
  Tuner control and LLRF are project specific, need to be provided by PIP-II



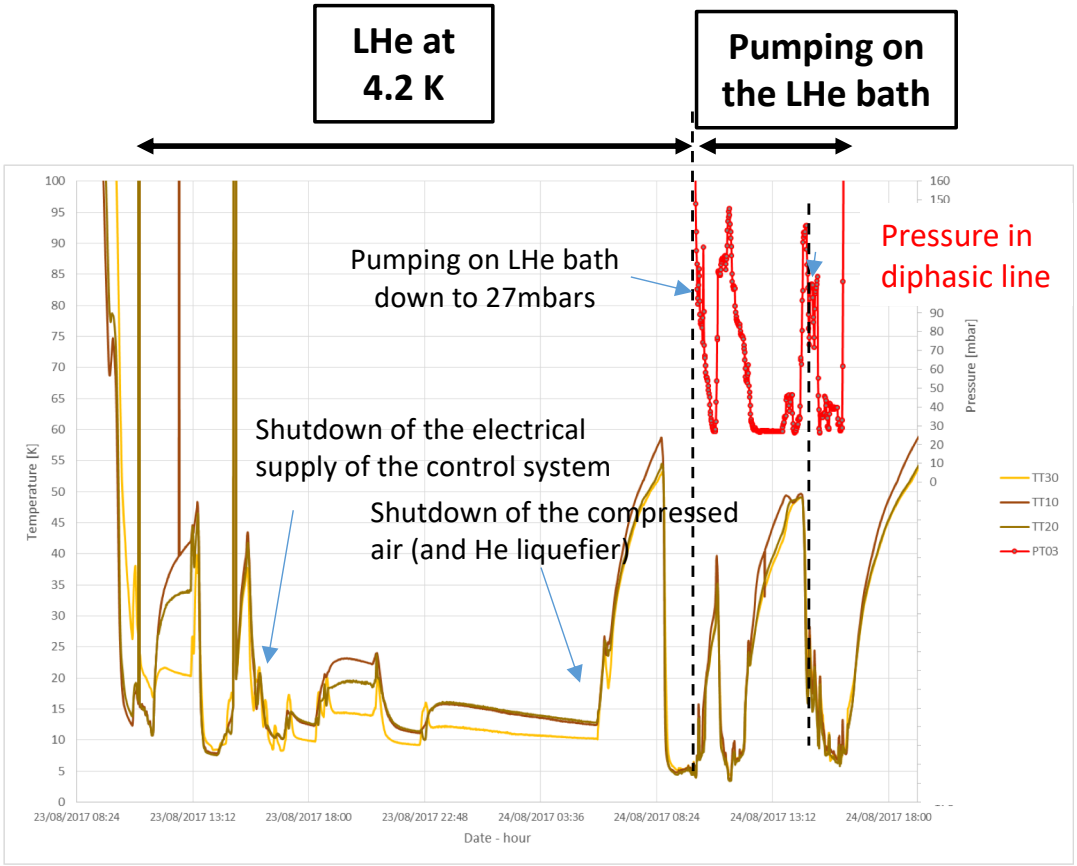
CEA EXPERIENCE ON CAVITY/CRYOMODULES TESTS

- Tests of elliptical and HWR dressed cavities in horizontal cryostat (CryHoLab):
  - 2 TTF elliptical cavities (XFEL prototype, 1.3 GHz on site)
  - 1 HIPPI (ESS like) elliptical cavities (704 MHz on site)
  - 2 IFMIF QWR cavity in satellite extension (Sathori, 175 MHz on loan)

- Tests of fully integrated cryomodules at CEA so:
  - MACSE (TFF prototype with 1 1.3 GHz elliptical cavity)
  - 12 Spiral2 Cryomodules (1 HWR cavity/cryomodule, 88 MHz)
  - 1 ESS cryomodule (4 elliptical cavities, 704 MHz)

- Tests of cryomodules integrated at CEA and tested elsewhere:
  - Soleil 352 MHz cryomodules (180 kW CW)
  - Super-3HC cryomodules with third harmonic cavities (1.5 GHz)

EG: PRELIMINARY TEST OF ESS M-ECCTD



Cryomodule at 2K for few hours with stable He level

1st measurement of static losses at 2K:

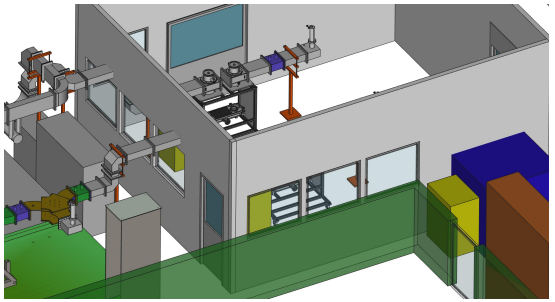
~ 23W (estimations = 17W)

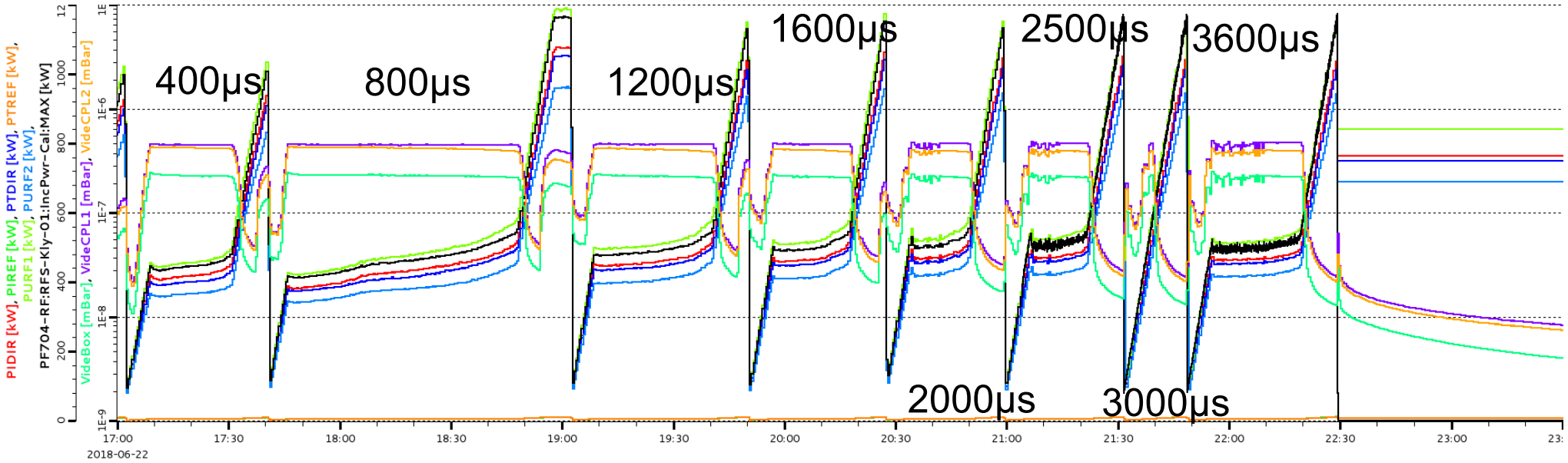
No dynamic loss measured (coupler window broke during doorknob installation)

LB650 COUPLER TESTS

- Conditioning sequence:
  - TW from 10µs pulses to CW, cycling from low to ~2*max power, regulating power on outgasing rate
  - SW from 10µs pulses to CW, cycling from low to ~2*max power, maximizing E and B on ceramic window with variable short circuit
  - Example of TW conditioning for ESS power coupler:

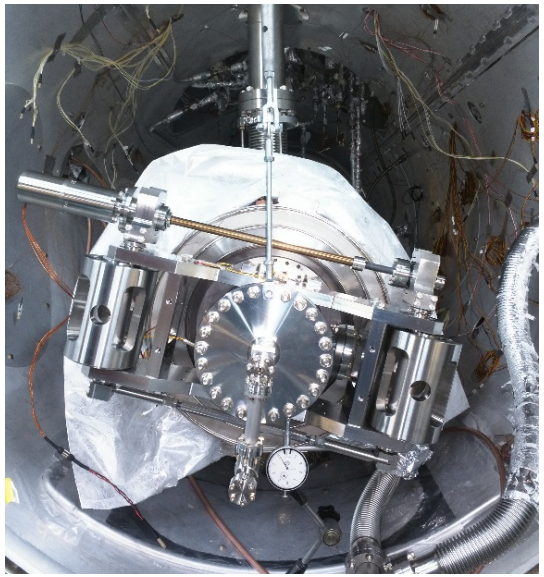
Coupler conditioning zone



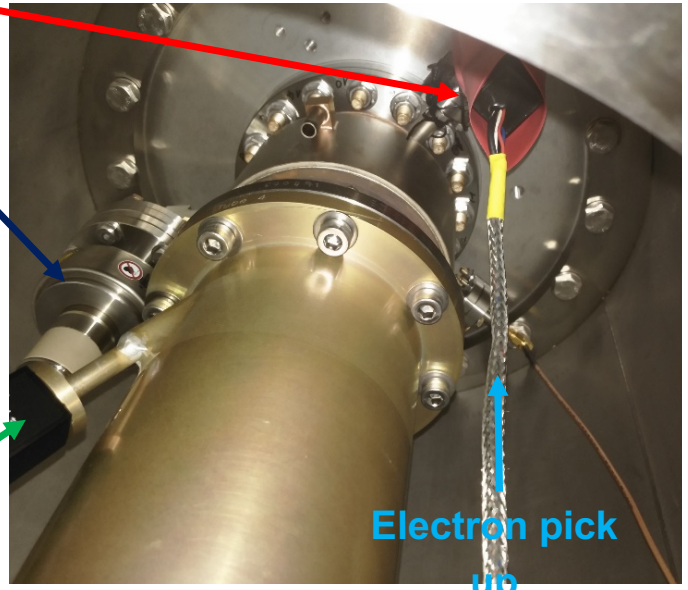


LB650 DRESSED CAVITY TESTS

- **The test of LB650 dressed cavity has the goals of verifying:**
  - the power coupler conditioning and performance with the cavity.
  - the cavity performance with the coupler + cryogenic loads
  - the cold tuning system (CTS) ability and performance.
  - the LLRF ability and performance, including microphonics studies.
  - the high power RF amplifier ability and performance in combination with the cavity and LLRF.



Implementation of the cavity and the coupler in the cryostat



- Will need to improve radiological protection of CryHoLab due to more stringent safety rules (estimated to ~150 k€ concrete shielding)

LB650 DRESSED CAVITY TESTS

List of tests for ESS dressed cavity at Uppsala

Warm test	Cool down	Cold test	Warm up
✓ Central cavity frequency and spectrum of HOM (pass band) ✓ Qe	Frequency shift/ He bath pressure variation	✓ Coupler cold conditioning	Frequency shift vs. T
		✓ Cavity conditioning	
		✓ Central frequency ✓ Loaded Q and Qe	
✓ Coupler warm conditioning		✓ Cavity level profile: let the LHe evaporate to low levels ✓ Effect of CV105 in heat load ✓ Cavity's power limit ✓ Effect of different FPC cooling temperatures in heat load ✓ Max load on the 2K pumps	
		✓ Q0 ✓ Dynamic heat load ✓ Max gradient ✓ Dynamic Lorentz force detuning	
		✓ Stabilization of the cavity field with LLRF using only RF compensation ✓ Dynamic Lorentz force detuning ✓ Tuning range of the slow step tuner	
		✓ Tuner related testing	

CRYOGENICS LOADS IN LB650 CRYOMODULE

Table 2.7: Cryogenic loads in SC cryomodules for operation in the CW regime

CM type	Number of CMs	Static loads per CM, (W)			Dynamic loads per CM, (W)	Total load at 2 K per CM, (W)
		70 K *	5 K *	2 K	2 K	2 K
LB650	11	48	16	2	58.1	60.1

Table 2.9: Maximum allowed heat loads per cryomodule

CM type	70 K	5 K	2 K
LB650	68 W	24 W	78 W

- Liquid Helium liquefier capacities most probably will have to be increased (80W max), even if cold 35-50K screen is LN_2 cooled.
- New 650 MHz RF wave guide system has to be installed in ESS/SARAF bunker

NON EXHAUSTIVE LIST OF CRYOMODULE TESTS

- Mostly the same philosophy as for dressed cavity tests:
  - Warm pass band measurement for 3 cavities string (HOM spectrum)
  - Warm couplers conditioning with cavities out of resonance
  - Cavities frequency shift and displacement during cool down to 4K
  - Low power cavity Q_L measurement, cold frequencies and HOM spectrum, tuner+piezo tests
  - Cool down to 2K and repeat above (maybe skip 4K step?)
  - Cold couplers conditioning with cavities out of resonance
  - Static heat loss measurement of cryomodule
  - Measure individual cavities performances at 2K at high RF power:
    - Q° and E_{acc} (other cavities detuned) with control of field emission
    - Dynamic heat loss measurement + cryo load for coupler
    - tuner+piezo range; LLRF + microphonics; Lorentz force detuning (?)
  - Caracterize full cryomodule performance with all cavities tuned at high RF power:
    - Total dynamic heat loss measurement
    - Final tuning+piezo adjustment and LLRF + microphonics

- Tests are mandatory for 1st pre-serie CM, preferred for 3 additional series CM